Fiber Optic Delay Tracking Experiment

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Future Linear Colliders will require a means of timing distribution that will be stable over time and temperature variations. Proposals for such accelerators include machines that are some thirty kilometers in length. The RF frequencies to be distributed are either in the hundreds of megahertz or higher. This precludes the use of coaxial cable due to excessive losses at these frequencies and cable lengths. Single mode fiber optics is the low loss choice for the distribution system. Regular single mode fiber has a temperature delay coefficient of approximately 30 picoseconds per kilometer per degree Centigrade. For a single path of 15 kilometers this would indicate 450 picoseconds delay change per degree C. This change would be unacceptable as it exceeds the tens of picoseconds stability for most of the proposed accelerators. Attempting temperature control of hundredths of a degree Centigrade is unrealistic. Some form of delay feedback is required. A system was proposed to provide higher stability and is shown in figure 1. A round trip transmission would be employed with phase or delay feedback split between the transmit and receive lengths of fiber. This technique requires the propagation delay constant of the two fibers to be very close, as the delay adjustments are applied equally to each length of fiber. If the differential time transmission is on the order of a few picoseconds, the system could provide a stable distribution for RF and timing signals. Before going through with a prototype test, it was decided to test how good two single mode fibers track as a function of time and seasonal temperature variations.

Figure 2 is the fiber tracking test set up. The Main Injector at Fermilab utilizes a number of single mode fiber communication links. Two spare fibers were available for this test. The fiber is Lucent 4DNX-24-BXC, which consists of 24 fibers packaged in a single jacket. The packaging has all 24 fibers in intimate contact with each other via a moisture repelling gel. The fiber is installed in communication ducts below the road that encircles the Main Injector and is looped into the ten service buildings that are located around the ring where they were jumpered for this test. The length of fiber around the ring is approximately 4.5 kilometers and is considered commensurate for the test. Measuring the propagation delay of such a long length is easily done in the frequency domain. Two correlator type notch filters were constructed with the fibers acting as the long leg of the filter. Such a filter provides a recursive notch such as that shown in the figure. For this experiment, the notch spacing is on the order of 42 KHz. The optical transmitter and receivers utilized are from Ortel[1] Corporation and have bandwidths exceeding 10 GHz. The transmitter is common to both filters. Both transmitter and receivers are temperature stabilized via Peltier thermoelectric coolers. The notches were adjusted to be a minimum of 20 dB deep by matching the gain of the long and short paths in each filter using microwave attenuators. An automated network analyzer measured the notches at 3 GHz with a resolution of 10 Hz. At 3 GHz, the harmonic number of the notch is on the order of 71,000 times the fundamental 42 KHz. A one-picosecond change in the length of the fiber corresponds to about a 125 Hz change in the location of the notch. The 10 Hz resolution hence allows measuring length changes of less than one picosecond. The notches in filter A and B were measured every 30 minutes from May 19, 2000 to December 1, 2000. (Several periods of data acquisition failures are noted on the plot.) To insure good frequency stability of the network analyzer, a GPS stabilized crystal oscillator source was used for the network analyzer reference. This crystal oscillator has a published stability of one part in 10^{-12} per day, which exceeds the requirement for this test.

It is difficult to measure the distributed temperature of the fiber around the ring. The outdoor temperature was data logged and averaged over a 96 hour period in an attempt to remove the daily temperature fluctuations that are not representative of the temperature of the buried fiber. Figure 3 shows the individual fiber delay and averaged outdoor temperature versus time. It is clear that the two fibers have a different delay slope over the period of the test. If the typical delay variation of 30 ps/deg C/kilometer is used, this would indicate that the average temperature change of the 4.5 kilometer fibers is on the order of 17-20 degrees C which very closely tracks the averaged outdoor temperature change.

Figure 4 depicts the propagation delay difference between the two fibers, which is the motivation for this test. The fibers track to several hundred picoseconds, not the desired value of tens of picoseconds. For this purpose, this technique for distribution is not viable for such linear accelerators. Methods utilizing one fiber for both transmit and receive via reflection are being pursued.[2]

References

1. Ortel Corporation, Alhambra, California, 91803
2. Josef Frisch et al, SLAC, The RF Phase Distribution and Timing System for the NLC.

NLC RF Timing Distribution Test at Fermilab

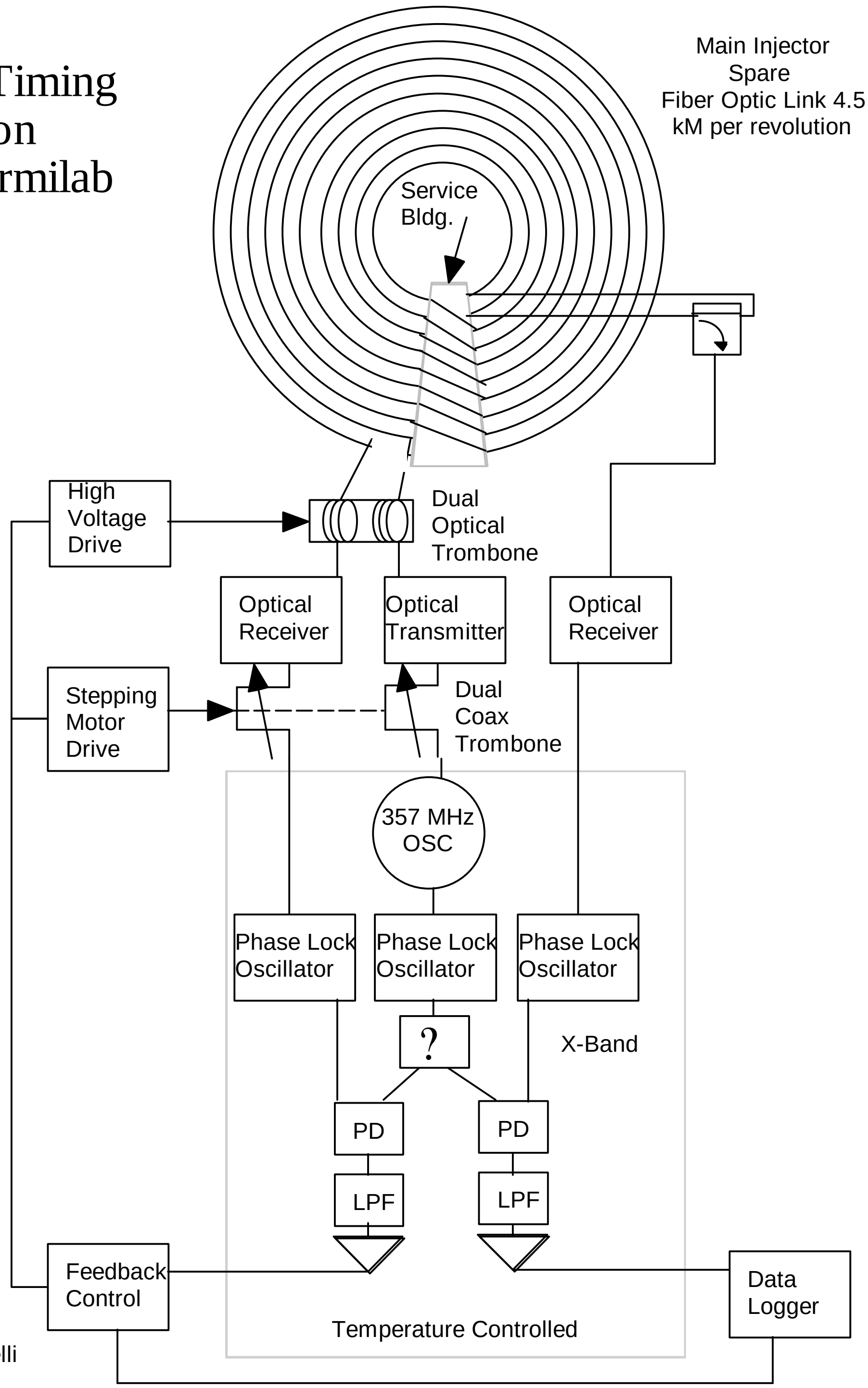

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Figure 1

Fiber Optic Delay Tracking Experiment

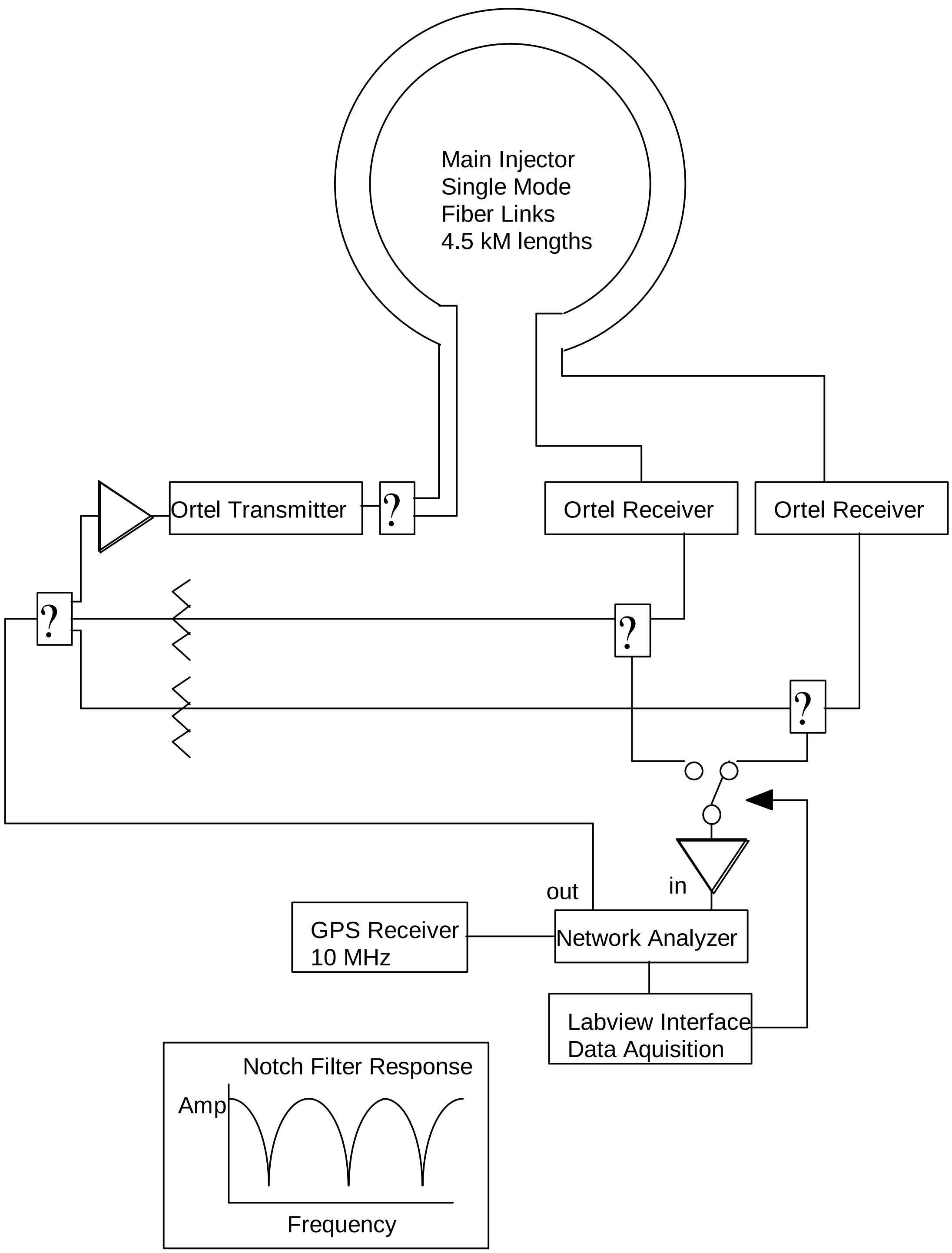
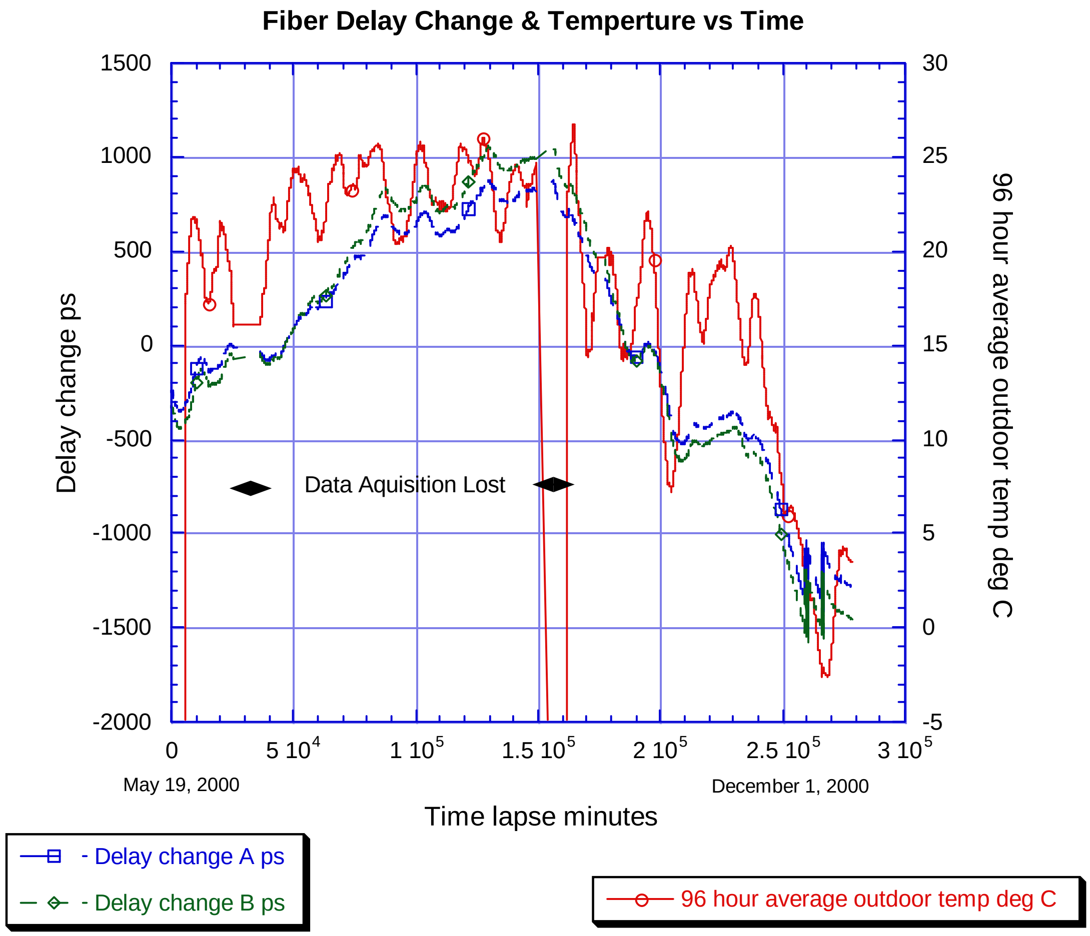


Figure 2



Fiber Delay Change & Temperture vs Time
1500
1000
500
0
-500
-1000
-1500
-2000
Delay change ps
30
25
20
15
10
5
0
-5
96 hour average outdoor temp deg C
Data Aquisition Lost
0
5 10^4
1 10^5
1.5 10^5
2 10^5
2.5 10^5
3 10^5
May 19, 2000
December 1, 2000
Time lapse minutes
- Delay change A ps
- Delay change B ps
96 hour average outdoor temp deg C

Figure 3

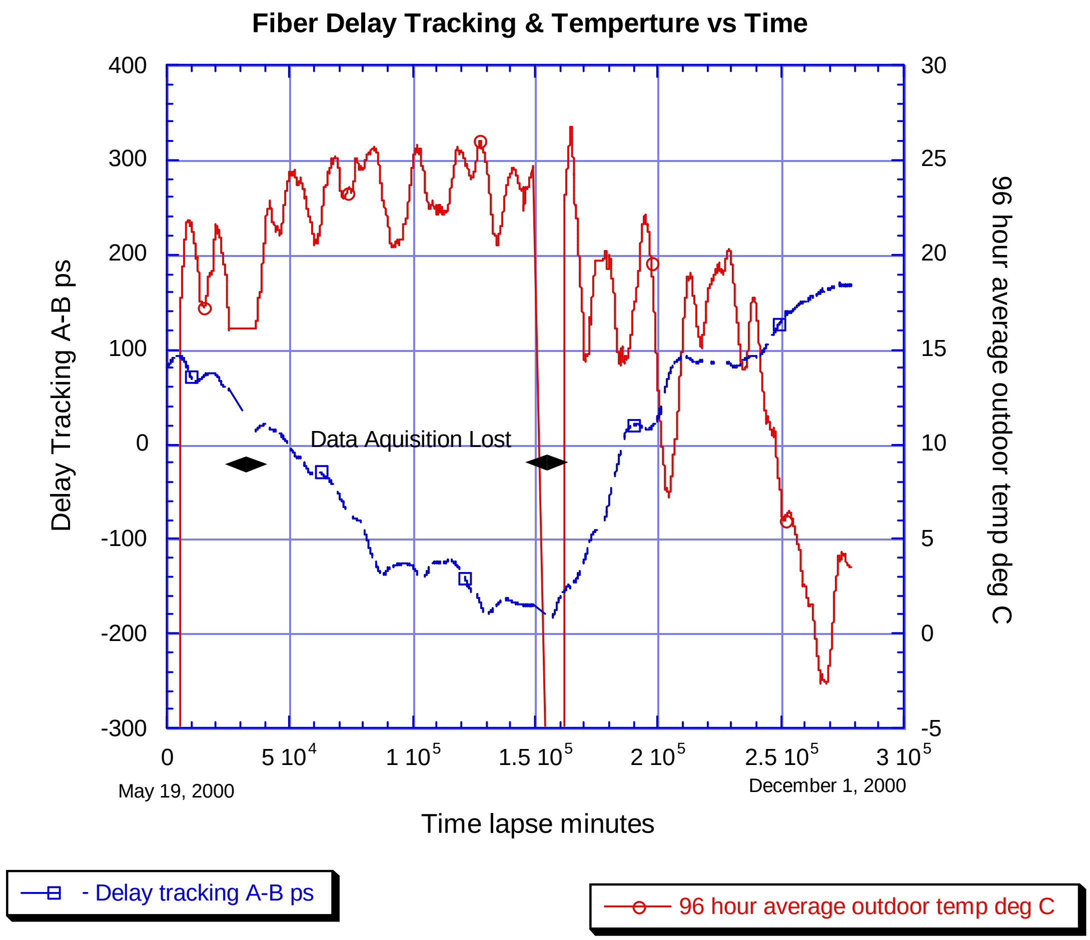

Fiber Delay Tracking & Temperture vs Time
Delay Tracking A-B ps
96 hour average outdoor temp deg C
Data Aquisition Lost
400
300
200
100
0
-100
-200
-300
30
25
20
15
10
5
0
-5
0
5 10^4
1 10^5
1.5 10^5
2 10^5
2.5 10^5
3 10^5
May 19, 2000
December 1, 2000
Time lapse minutes
- Delay tracking A-B ps
96 hour average outdoor temp deg C

Figure 4